INNOVATIVE TOOLS, METHODS, AND ANALYSIS:

SOCIAL SCIENCE PERSPECTIVES ON CLIMATE CHANGE, PART 3

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Abstract

Humans both contribute to and are impacted by climate change. Understanding the interactions between human societies and climate has long been a major goal of fundamental and applied socio-ecological research in archaeology, geography, sociology, and cultural anthropology; this research employs a wide variety of quantitative and qualitative approaches and datasets. To address the dynamic interactions within and between disciplinary approaches, this paper synthesizes recently developed innovative tools, methods, and analyses. Advances in geospatial tools, including remote-sensing technologies, and approaches to modeling, including agent-based modeling, take advantage of and yield ever-larger databases. Innovations that take advantage of "Big Data" are changing the spatial and temporal scope of inquiry. Databases of cellphone-call data, for example, allow near-real time monitoring of human responses to disasters. Survey data can be combined with climate and weather records or environmental characteristics to understand how environmental factors interact with public perceptions, behaviors, and attitudes towards policies. Information from interviews and long-term participant observation helps researchers understand the impacts of climate change not only on people's beliefs and desires but also on other domains of their lives, such as culture, health, and family. To find patterns of human/environment interactions in more distant times, archaeologists employ a large suite of temporally precise proxies for climate change in conjunction with an improving record of human impacts on the environment and responses to climate change.

We begin the paper by discussing the importance of a synthesis framework and the contributions of social science, especially archaeology, geography, sociology, and cultural anthropology, to understanding climate change, highlighting commonalities and differences of those four social sciences. We argue that a better understanding of social science tools, methods, and analyses will enhance climate-change research and provide accessible synthesis products that can inform decision making and resource management. We then discuss how each discipline rigorously collects and analyzes quantitative and qualitative data, including the pertinent statistical and computational tools. In the next section, we discuss methods for synthesizing information and creating narratives that support actionable science that federal agencies, especially the U.S. Global Change Research Program, can use. We conclude by identifying key insights and future directions that will enhance the translation of social science research into actionable applications.

Introduction

The mission of the U.S. Global Change Research Program (USGCRP) is "to build a knowledge base that informs human responses to climate and global change through coordinated and integrated Federal programs of outreach, education, communication, and decision support" (USGCRP, 2017). This capacity building primarily takes place through the engagement of interagency working groups that contribute to improved descriptions and synthetic assessments of current climates and those of the recent past. Products such as the National Climate Assessment aid federal agencies in building skills toward forecasting future climates, communicating about and managing risk, and addressing a variety of decision-support needs.

In this paper, we are concerned with tools, methods, and analyses because one of the special charges of the Social Science Coordinating Committee (SSCC) at USGCRP is to consider how the integration of social science perspectives, data, methods, tools and analyses can contribute to better understanding the nature and magnitude of human response to climate changes (Figure 1). This response potentially includes mitigation, defined as efforts or actions to reduce the human contribution to the planetary greenhouse effect (Bierbaum et al., 2014, p. 671), and adaptation, defined as action to prepare for and adjust to new conditions (Jacoby et al., 2014, p. 649).

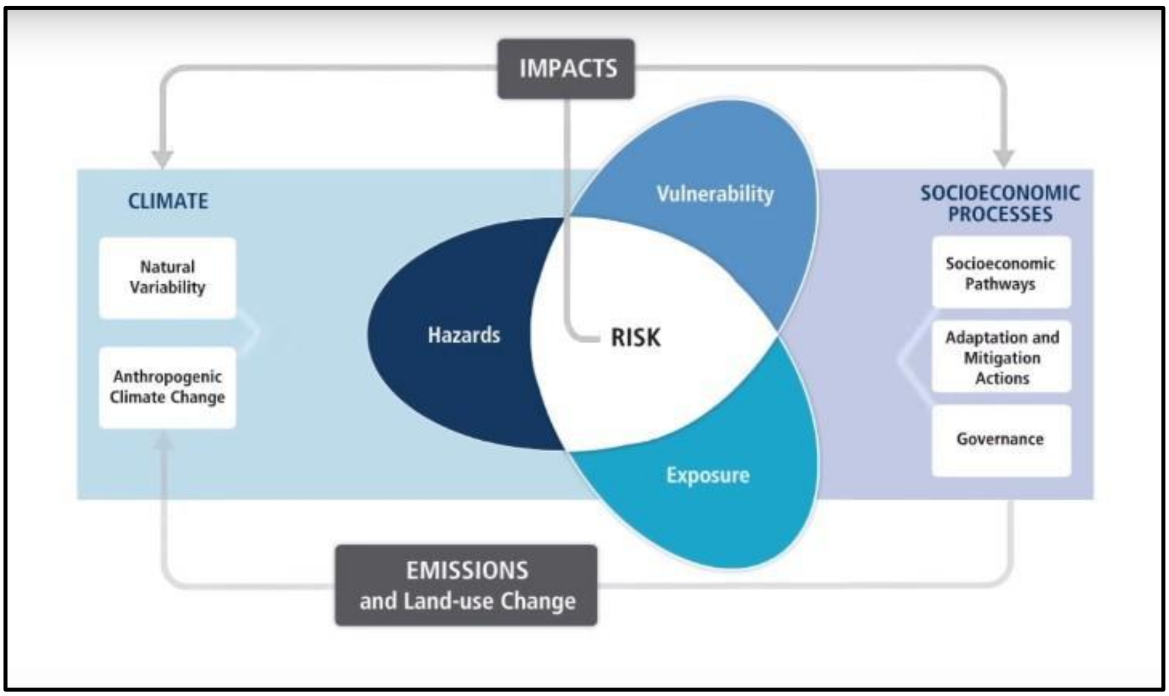


Figure 1. Climate-change-related risks are dependent on changes in the climatic system and on socio-economic processes. Policies and actions related to adaptation and mitigation help reduce the risks associated with climate change and variability. Source: Intergovernmental Panel on Climate Change (2014, p. 3).

By "social sciences," we mean here an array of disciplines that use a diverse set of approaches, data, and tools to ask and answer questions and synthesize findings about people and societies over time and space. The findings may take the form of qualitative narratives or quantitative survey outputs, both that explore the complex interactions between human and natural systems under climate change. In this paper, we utilize the approaches of four complementary and intersecting social sciences that use tools, methods, and analyses that often cut across disciplinary lines, thus connecting natural sciences and social sciences; provide robust datasets and subsequent analysis; and connect with sources of local and indigenous knowledge on resource-management practices. Those disciplines are archaeology, cultural anthropology, geography, and sociology.

As we highlight commonalities and differences of those four social sciences, we pose these central questions about the relevant tools, methods, and analysis: What tools can help us better understand interacting socio-economic and physical drivers that lead to plausible mitigation strategies and participatory governance structures? How do we measure and understand (possibly changing) concepts of risk, tradeoffs, and fairness? What approaches and tools can help us understand how social factors, interacting with ecological systems, enable or prevent effective adaptation to the immediate and projected effects of climate change? How can these tools help us understand the types of adaptation measures that different types of communities can effectively apply? What approaches and tools can help us understand how social factors increase or decrease vulnerability or resilience in the face of climate change? How can these tools be used to identify interventions that can increase resiliency in different types of communities? How can these tools facilitate transdisciplinary collaboration with affected communities, ground responses in indigenous and local knowledge frameworks, and promote local stakeholder engagement and continued adaptive practices in situ?

In the following sections, we begin by discussing the importance of a synthesis framework and the contributions of social science to understanding climate change. We argue that a better understanding of social science tools, methods, and analyses will enhance climate-change research and provide accessible synthesis products that can inform decision making and resource management. Second, we discuss how each discipline collects and analyzes quantitative and qualitative data, including the application of pertinent statistical and computational tools. In the third section, we discuss methods for synthesizing information and creating narratives that support actionable science that federal agencies, especially the USGCRP, can use. In the conclusion, we identify key insights and future directions that will enhance the translation of social science research into actionable applications.

Socio-Ecological Systems: A Synthesis Framework

Fundamental to developing methods to study the human dimensions of climate change is adopting a system-oriented perspective. Defining “socio-ecological systems” as linked systems of people and nature, Berkes and Folke (1998) emphasize that humans are part of, not apart from, nature. Studies that employ a socio-ecological systems perspective embrace elements of both social and natural sciences, but their primary interest is in the intersections and interactions between those types of science. Using a socio-ecological systems perspective, we do not simply pose one question: What is the contribution of social science to understanding climate change? Rather, we ask, following the National Climate Assessment (USGCRP, 2014): In the context of climate-change research, how can acknowledging the interconnectedness of social and natural systems facilitate a better understanding of the ways environmental, cultural, and social systems interact and interdepend? How can we use that understanding to help decision makers identify the information they need to manage risk, understand vulnerability, and develop multi-level strategies for mitigation and adaptation?

There has been a limited amount of research to date on these subjects because, although the need for such research is clear, the complex problems located at the socio-ecological interface defy simple solutions. When we consider the multiple dimensions of a given issue, including human-environment interactions and feedbacks, an intervention in one area may aggravate existing problems, and new, unforeseen aspects can emerge and bring unwanted results. “Wicked problems,” or issues that result in such cascading effects, often are a combination of natural resource issues and human responses, such as war and migration (Holm et al., 2015), and require a multi-disciplinary systems approach. To illustrate these types of problems and the difficulties in addressing their many components, the National Climate Assessment traces ongoing and predicted impacts of climate change and climate extremes throughout the United States. It addresses subjects such as the community-health effects of heat waves, changes in the timing and capacity of seasonal floods, and food stability and security.

Facilitating actionable research and responses to the human dimensions of global change requires an accelerated integration of social science tools, methods, and analyses into the assessment process; this integrated approach will aid in understanding underlying feedback loops operating on multiple scales. Examining the variations in the impacts related to different climate-change outcomes in different socio-ecological systems provides insight into the uncertainties, unintended consequences, and complexity of systems that are crucial to effective policy prescriptions. Understanding what happens and why it happens not only informs the development of policy and technology solutions but also helps predict their consequences.

The scientific modeling community uses climate projections to ascertain the range of future conditions, allowing for a wide band of potential outcomes and intersections. One type of projection is the climate simulation, which is based on assumptions about human behavior’s influence on future carbon emissions. Simulations present a collection of scenarios, each representing one possible projection based on analysis of a narrow set of social and economic characteristics such as population, industrial growth, and emissions (Moss et al., 2010; National Research Council, 2011; Van Vuuren et al., 2012). Simulations tend, however, to leave out other important factors, including social vulnerability and social resilience. Vulnerability includes poverty rates, the age of the infrastructure and housing, ease of migration, and community connectedness, while resilience involves the functionality of neighborhood and urban governance structures, including their ability to relocate populations. All are important determinants of the drivers and impacts of climate change, in terms of damages and strategies for adaptation and mitigation.

In socio-ecological system studies, translation and synthesis bridge the gap between research and policy. The translation of research is an active, multilateral process that involves dialogue and collaboration between the users and the generators of information, and occurs within the larger context of scientific knowledge and stakeholder experiences. Critical to research translation is the synthesis of ideas, data, and research results that, once combined into a whole, supports development of a theory or system. By developing a broad understanding of a complex system, such syntheses produce and inform actionable knowledge. To succeed, these efforts depend on the careful and inclusive process of fundamental problem formulation in which each knowledge stream is linked to a meta-theoretical framework. The synthesis should lead to actionable information that informs policy makers, affected communities, and other stakeholders.

Since 2007, archaeologists have increasingly worked closely with historians, cultural anthropologists, and communities retaining local and traditional knowledge (LTK) to open the black box of human decision making, cognition, and resource-management practices. This focus potentially unites the four social science disciplines participating in this white paper, as well as the burgeoning field of environmental humanities (Holm et al., 2015).

Social Science Contributions in Data, Methods, and Analysis

Quantitative and qualitative approaches—used separately or in combination—enable social scientists to ask questions about and understand the interactions and interdependencies between humans and climate. Quantitative approaches help characterize and understand what is occurring; test hypotheses; and measure associations among social and cultural factors, physical climate change, and climate-change impacts. Qualitative approaches provide more nuanced understandings of whys and hows, such as why an association exists, and how a specific social or cultural factor relates to a specific impact. Better understanding of what is happening and why it is happening can inform potential policy or technology solutions and can suggest unintended consequences of such initiatives. Qualitative information includes interviews, ethnography, oral histories, archival documentation, video and audio recordings, photographs, and modeling. All this information can be quantified, but at the risk of compromising critical human dimensions. To capture those dimensions, a mixed-methods approach can be used; the combined use of quantitative and qualitative methods draws on their strengths and overcomes their weaknesses.

The ideal framework of social science research encourages the exploration and analysis of human behavior at multiple scales from the individual to communities and institutions.

The ideal framework of social science research encourages the exploration and analysis of human behavior at multiple scales from the individual to communities and institutions. One important tool is agent-based modeling (ABM), which generates a computer model of a landscape by integrating quantitative and qualitative approaches; the model is developed using physical-landscape characteristics integrated into a geographic information system (GIS) and incorporates the dynamic interaction of agents such as individuals, households, or communities (Kohler & Gumeman, 2000). These computationally intensive approaches comprehensively integrate social and human behavioral processes, using quantitative and qualitative data within an Earth system modeling frame, enabling powerful syntheses of socio-ecological systems. While earlier ABMs relied on simplified representations of human decision making, recent models capture the dynamism of human behavioral processes (Evans, Phanvilay, Fox, & Vogler, 2011). One classification system aggregates variation in the decision-making processes of diverse agents; Rounsevell and colleagues (2014), who developed the system, suggest ways that traditional social-science data-collection instruments, such as surveys and censuses, can help classify the diverse agents' decision-making, and how to aggregate results drawn from the small scale—an individual or a few actors—to the scale of a community, with its many diverse actors and competing interests.

In this essay, we identify tools, methods, and analyses that are most applicable to different temporal and spatial scales, and that have the greatest potential for improving our capability to explain and predict natural phenomena and human behaviors. That improved ability may support recommendations for mitigation, adaptation, and resiliency strategies in the face of climate change.

Archaeology: A Distributed Observing Network of the Past

Social scientists employ two classes of methods to understand the relationship between people and climates. The first is deductive: research begins by building models, and their implications are deduced through logic or simulation. The second is pattern recognition: research examines instances of climate change or anthropogenic impact around the world, and then asks how different types of societies have adapted.

Because climate change and human action together cause environmental change, records of social, cultural, and environmental change provide a rich set of raw materials for predicting variability in future human responses to climate change. As the unique discipline that studies people and culture through their material remains, including the vast pre-literate record of our species, archaeology enlarges the sample of patterns available for analysis. Routinely employing tools and methods from across many disciplines, archaeology is a bridging discipline at the intersection of social and natural sciences (Chapman & Wylie 2016, p. 11). The archaeological record is transdisciplinary in that planners, climate scientists, and many other scientists use archaeological data and perspectives.

To manage anthropogenic effects on the environment, we must understand socio-environmental relationships. That understanding logically begins with questions about where people lived and for how long, what actions they took, and how those actions interacted with the environment (Foster, Paciulli, & Goldstein, 2016, pp. 1-15). Archaeologists suggest viewing the archaeological record as a "Distributed Observing Network of the Past" (DONOP) in which archaeological sites throughout the world provide records of human-environment interactions across space and time (Sandweiss & Kelley, 2012).

The materials with which archaeology is concerned include artifacts and ecofacts, human-made and organic materials that may be collected during survey and excavation, which are fundamental archaeological techniques for gathering empirical data. When they do not have direct climatic data, archaeologists use proxy data: records of natural phenomena that have been directly impacted by climatic change. These datasets include records of fluctuations in the amount of wheat or grapes harvested at different times; paleoecological data, including sediments from lakes, oceans, and glaciers, yielding fossil pollen and isotope-bearing materials; and sequences of tree rings that yield climatic information (Weiss, 2017, pp. 2-3). Archaeological data include botanical and faunal species and frequencies, and geomorphological data about water and land forms (Rosen, 2007, p.17).

Analyzing the DONOP provides insights into inherited landscapes that have current and potential future legacies (Foster et al., 2016, pp. 1-15). For example, ancient middens contain faunal remains that make possible species identifications that are useful for understanding the breadth of past distribution of many animals, some now rare or extinct (Lyman, 2012). DNA from recovered remains of plants, animals, and people adds unprecedented detail to reconstructions of past distribution and greatly enhances archaeologists' ability to identify processes, such as dispersal and interbreeding, that provide evidence of human migration (Allentoft et al., 2015 Kemp et al., 2017; Nielsen et al., 2017).

By using the DONOP framework, archaeologists increasingly contribute to scientific studies of community ecology, land-use sustainability, and human activities' influence on greenhouse gas (GHG) emissions (Murphy & Fuller, 2017). An important current concern is to understand how past patterns of climate change and human land use (Ellis et al., 2013) have affected biological diversity and the resilience of communities experiencing environmental change. Related research also addresses the Pleistocene human expansions out of Africa, through decoding human genetic variation, and the extinction of Neanderthals (Henn, Cavalli-Sforza, & Feldman, 2012; Pääbo et al., 2004). Numerous projects consider farming, in regard to both its expansion and the frequency with which early farming societies declined or collapsed (Schwindt et al., 2016; Downey, Haas, & Shennan, 2016). Many other studies examine the related spread of farming and languages (Biehl, 2015; Bocquet‐Appel, Naji, Vander Linden, & Kozlowki, 2009; Bramanti et al., 2009; Diamond & Bellwood, 2003; Edwards et al., 2007; Haak et al., 2010; Lemmen, Gronenborn, & Wirtz, 2011).

Archaeological sites throughout the world provide records of human-environment interactions across space and time: a Distributed Observing Network of the Past.

In supplying a human dimension to the reconstruction of pre-industrial climate, the DONOP yields a deep, varied picture of the human condition and that of our planet. Focusing on aspects of the archaeological record that are site specific, or are composed of larger regional pictures built from numerous local records, enables analysis across multiple spatial scales, using geospatial tools such as GIS and remote sensing. In providing unique glimpses of life and environment in pre-Anthropocene epochs, archaeology enables us to better understand the onset of the Anthropocene (Erlandson & Braje, 2013; Smith & Zeder, 2013).

Determining the suite of resources available to humans at particular times and places is a fundamental task because resources depend on both local climatic regimes and human use. Comparing the potential resources with those that people actually used is critical for assessing possible human over-use or depression of resources. Although it may be thought that pre-industrial populations had less impact on the environment than modern people have, since the 1980s archaeologists have recognized just how common resource depression was among the rapidly growing populations of Neolithic societies. A typical response to such depression is intensification of resource use, which frequently contributes to many unintended consequences including vulnerability to climate downturns. For example, Pueblo societies of the U.S. Southwest depleted the pinyon-juniper woodlands in some areas and depressed deer populations in even larger zones (Kohler & Matthews, 1988; Schollmeyer & Driver, 2013). In the 11^{th} century A.D., the declining availability of deer stimulated Pueblo people to raise more turkey and feed it maize. That change put them at risk in the 13^{th} century A.D., when cooling and desiccation decreased maize production, and contributed to their mass emigration (Bocinsky & Kohler, 2014).

The recent increase in the sophistication of analysis of stable isotopes, obtained from preserved faunal/bone samples (Kristiansen, 2014), to retrieve information on climate, human diet, human mobility, and object provenance has assisted scientists in reconstructing such causal chains, as through demonstrating the dietary importance of maize for turkeys and humans (Coltrain, Janetski, & Carlyle, 2006; Rawlings & Driver, 2010). Similarly, by analyzing a finely dated $\delta^{18}O$ climate record on a stalagmite that grew continuously from 40 B.C. to A.D. 2006 in a cave in Belize, scientists concluded that drought-induced decreases in maize production contributed strongly to the disintegration of the Classic Maya lowland civilization (Kennett et al., 2012). In this case of collapse, as in many others, there was no simple cause: production was likely insufficient to the needs of a population that had been growing rapidly for centuries; the shortage set off warfare as well as population decline.

Drought-induced decreases in maize production contributed strongly to the disintegration of the Classic Maya lowland civilization.

In modeling changes in world vegetation over the Holocene, changes in climate and human land use are taken into account (Ellis et al., 2013) because humans began to make large-scale alterations to the global ecosystem at least 3,000 years ago. Species-distribution, or eco-cultural niche, modeling builds quantitative, predictive models of relationships between species or cultures and environments. For example, Banks, Antunes, Rigaud, and d'Errico (2013) found that the three main cultures spreading Neolithic lifeways across Europe between 6500 and 4000 B.C. occupied distinct ecological niches.

While many scientists identify human activities as the primary cause of the rapid acceleration of climate change observed over the last century, human influence in earlier times also has been identified. Zubrow points out human effects that were evident as long as 12,000 years ago and led to "the deforestation of the world beginning about 10,000 B.C., and the increasing desertification of the Middle East and other parts of the world" (2016, p. 281). Even then, social systems interacted with major and sometimes rapid human-caused environmental change. Desertification, also beginning about 10,000 years ago, is frequently a byproduct of overgrazing and diminishes biological diversity. That decrease in turn cascades into changes in soil conservation, surface-water regulation, local climate, and the amount of carbon released into the atmosphere; the last especially impacts global climate change (Whitford & Wade, 2002, pp. 275-304). Deforestation began when agriculture began, as people first used fire to clear land for crops. Beginning around 9000 B.C., deforestation increased rapidly; by 1000 B.C., in many areas 50–70 percent of land was deforested. Slash-and-burn agriculture, along with efficiently bringing new land into production and returning minerals to the soil, was often an ownership strategy and an investment (Angelsen, 1999; Kaplan, Krumhardt, & Zimmermann, 2009).

Written records, once they become available, provide another line of evidence for understanding human decision making, especially in regard to the thresholds of social survival and the tipping points or specific incidents that provoked a change. In the late 4th and early 3rd millennia B.C., burgeoning communities in alluvial plains along Iraq's Tigris-Euphrates River system had to make many adjustments to the increasingly arid environment. Using combined information from ancient written records, archaeological excavation and survey material, and geological data, scientists have plotted spatial and temporally dynamic relationships between those river systems

1. HUMAN ADAPTATION TO THE 8.2 CLIMATE EVENT

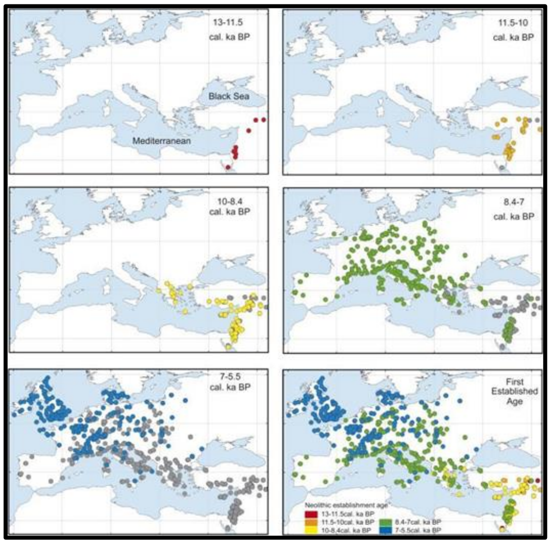


Figure 2 (left). Maps of human migration following the 8.2 climatic event show the location of sites recording the first evidence for the Neolithic across Europe, Anatolia and the Near East. For each time slice, colored dots indicate sites newly established, and gray dots represent sites previously established. Source: Turney and Brown (2007, p. 2037).

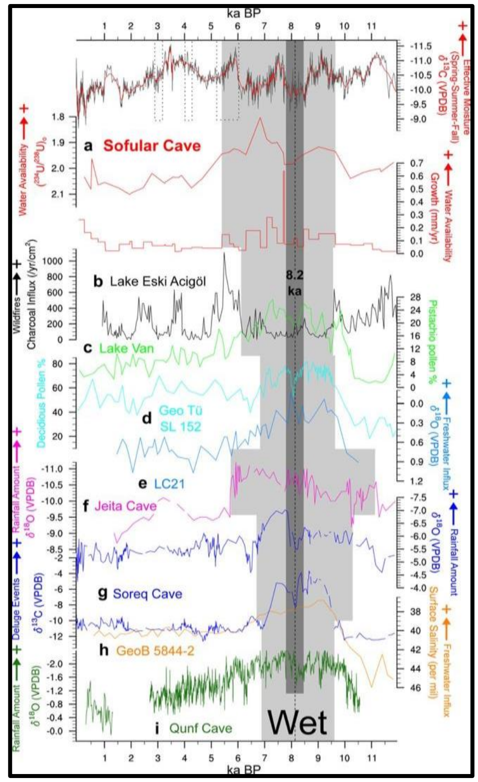


Figure 3 (right). Climate proxies in Anatolia highlighting the 8.2 climatic event. Sea core LC21 in the Eastern Mediterranean east of Crete yielded data that point toward a cold spell between 6400 and 5800 cal B.C.; the same is true for Sofular Cave in Northern Anatolia, where sampled speleothem evidence for drier conditions around 6200 cal B.C. provides the first hints that Central Anatolia was similarly affected by the event. Source: Göktürk et al. (2011, Fig. 9, p. 2440).

Recent research at the Neolithic site of Çatalhöyük, Turkey (Ryan & Rosen, 2016; Willet et al., 2016) yielded paleo-environmental evidence for a climatic event 8,200 years ago (usually called "the 8.2 event"). Those findings suggest that Neolithic populations had to cope with climate change that likely impacted cereal agriculture, particularly in marginal environmentsand that those changes caused people to move west into Western Anatolia and across Europe (Figure 2; Biehl, 2012). That climate event may be correlated with cave formations (speleothems) from the Eastern Mediterranean and Anatolia (Figure 3). An arid phase 8,200 years ago is also suggested in the Dead Sea sedimentary record. Proxy data suggest that cooling occurred mainly in the Northern Atlantic, indicating that the event was most likely caused by meltwater and that the location of the cooling corresponds temporally with climatic disruptions to summer monsoon weather systems. Evidence from Lake Van in Eastern Anatolia shows contemporary changes in the pollen record, but indicates greater humidity rather than aridity.

and settlements (Hritz, 2010, 2014; Hritz, Poumelle, & Smith, 2012). The growing agricultural communities' techniques to maintain access to river waters moved from tapping into existing river channels, through using first a hybrid of natural and managed river channels and then artificial channel systems that required constant maintenance (Adams, 1981; Algaze, 2008). Some but not all early communities grew into urban centers and thrived for centuries.

Archaeological data and techniques help identify common characteristics, including behaviors and planning strategies, that contributed to community survival. Archaeology thus provides insights into instances when people interacted with the environment and coped with resource changes at various scales—and when they did not, so that resilience thresholds were tipped.

The Impact of Computation in Understanding Socio-environmental Interactions

Archaeological and related modeling of coupled natural and human systems over large areas and long time spans generally has a large computational component (d'Alpoim Guedes, Crabtree, Bocinsky, & Kohler, 2016). Several ongoing projects, including Synthesizing Knowledge of Past Environments (SKOPE; www.openskope.org) and dataARC (www.data-arc.org; Strawhacker et al., 2015), aim to improve archaeological capacity in this area, especially through developing cyber-infrastructure that makes it easy for scientists to access environmental and climatic records and process them in ways that help answer specific questions.

> *The U.S. Southwest will likely soon experience conditions more severe than those that caused major disruptions to the area's pre-Hispanic societies.*

One active area is modeling local climates across a landscape at high temporal and spatial resolution, using interpolated and downscaled climate data from multiple climate proxies. Such reconstruction techniques are especially useful for understanding the distributions through time of farmers and their cultigens, which are particularly sensitive to the effects of climatic variability. D'Alpoim Guedes, Manning, and Bocinsky (2016) modeled 5,500 years of changes in niches for cultivated wheat and barley on the Tibetan Plateau. Similarly, for a vast area on the U.S. Colorado Plateau, Bocinsky, Rush, Kintigh and Kohler (2016) used tree-ring climate records and computer-intensive methods to construct high-spatial-resolution maps showing where precipitation would have allowed unirrigated maize cultivation for every year from A.D. 50 to 1400. Correlating this maize-niche reconstruction to building, as documented by tree-ring dates from archaeological sites, they found that the demise of early Southwest villages around 900, the 12th-century breakdown of the regional polity, and farmers' 13th-century departure from the region all corresponded to significant downturns in maize production in the occupied places (Box 2).

The archaeological record provides a long narrative of human-environment interactions and reactions. In response to specific questions, this record can inform planning for mitigation and adaptation as it provides evidence based on a series of human behaviors through time in various environments and societies. Forecasts paired with the archaeological record provide a human calibration for the nature and severity of possible future social crises. The strength of the archaeological record lies not in its ability to make specific predictions about the future of our society. After all, both current population sizes and the technological repertoire available to

2. MAIZE, DROUGHT, AND MIGRATION IN THE U.S. SOUTHWEST

From about A.D. 900 through the late 1200s, Pueblo and Chaco societies in the northern U.S. Southwest experienced social problems ranging from the early-900s demise of the Pueblo I villages, through the mid-1100s breakdown of the Chaco regional system, to the area's late-1200s depopulation—all accompanied by significant increases in violence in the central Mesa Verde region (Cole, 2012, Figure 13.5).

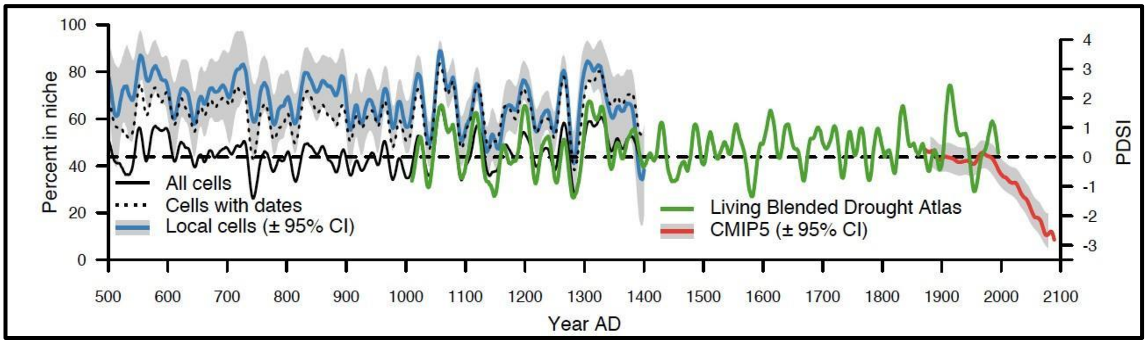


Figure 4. The maize niche and its relation to droughts in the U.S. northern Southwest, A.D. 500–1400, and climate projections through 2100. Source: d'Alpoim Guedes, Crabtree, et al. (2016, Fig. 4, p. 14487).

In Figure 4, for A.D. 500–1400 three lines (left) report the (smoothed) proportion of the maize niche for three different spatial extents. The blue line and gray confidence interval show the proportion of cells within the niche known to be occupied in the current year or previous three years. The dotted line reports the proportion of all cells within the current niche known to have been occupied at any time between A.D. 500 and 1400.The solid black line represents the proportion of cells within the niche within the entire 691,200 30–arc sec cells in the study area. (Each cell represents a square about 800-x-800 m.) All three lines record downturns accompanying the Pueblo I village demise, Chaco system breakdown, and larger regional depopulation. The green line reports a measure of drought derived using a different technique for a larger but overlapping area, which also depends on the tree-ring record. The green line is highly correlated with the proportions of cells in the maize niche. The red line, which predicts future drought within the same area reported by the green line, is based on an ensemble of global climate models running under a business-as-usual scenario (Cook, Ault, & Smerdon, 2015).

These models predict future droughts, driven largely by increasing greenhouse gases in the atmosphere, that will occur by around A.D. 2050 and surpass the worst droughts previously recorded for that area. The Southwest will likely soon experience conditions more severe than those that caused major disruptions to the area's pre-Hispanic societies.

address emerging problems are now vastly greater than at any time in prehistory. Rather, the archaeological record suggests that technological solutions have tended to raise new problems that additional technological solutions did not always successfully address. For contemporary society, the many examples of inability to adapt that have been documented by the archaeological record—which were unavailable to past societies—now offer cautionary lessons about the limits of growth and technology.

Human Geography: Geospatial Techniques in Human Dimensions of Climate-Change Research

Geographic research employs a range of data collected at various scales. Subjects of recent contributions concerning human dimensions of climate change include managing, measuring, and valuing carbon dynamics (Dilling & Failey, 2012; Poulter et al., 2014); identifying socioeconomic and biophysical determinants of human and ecosystem vulnerability and adaptive capacities (Runfola et al., 2017; Shukla, Sachdeva, & Joshi, 2016); monitoring land use and land cover change (Hansen et al., 2014; Hmimina et al., 2013); and assessing short- and long-term biodiversity loss and conservation outcomes (Nagendra et al., 2013; Segan, Murray, & Watson, 2016; Watson, Iwamura, & Butt, 2013).

Small-scale case studies help support in-depth, context-specific insights into climate vulnerability and adaptation (Eisenack et al., 2014; McDowell, Ford, & Jones, 2016). Geospatial tools, methods, and analyses on climate-change research often employ geospatial data fusion or leverage geo-referenced cell-phone or social-media data, much of which is Big Data. Such innovative blended-data approaches well illustrate how geospatial data and tools inform understandings of human vulnerability, resilience, and adaptation to climate change—information that is particularly useful for disaster management.

The continued and accelerated development of sophisticated geospatial tools for collecting data precisely located in space and time includes aerial and satellite remote sensors, geographic information systems, and global positioning systems. Remote sensing technology has brought global data to the front of analysis. Light detection and ranging (Lidar) and drone technology not only can provide extremely precise, very high-resolution measurements but also can facilitate making data available to researchers (Giovanni Biaocchi, pers. comm.). Spatial coordinates in socio-economic censuses and surveys can be linked with those in other types of datasets. As larger and more comprehensive databases, such as those produced by geo-demographic marketing, and social-network exchanges linked to spatial locations are becoming routinely available, their use requires attention to issues of privacy and ethics, and their analysis requires ever-more advanced expertise and collaboration involving applied math, spatial analysis, parallel programming, and Bayesian statistics (Giovanni Biaocchi, pers. comm.).

Geospatial data fusion has been applied to climate-related questions at scales from the local to the global. Geo-referenced data are integrated with those from other physical datasets, which include elevation and stream-gauge data, and socio-economic datasets, which include censuses and household surveys. Combined analysis of geospatial and other data helps researchers link drivers, impacts, and responses to places and times, and then clarify causal relationships.

Remote Sensing and Data Layering

Examinations of the impacts of incremental and transformative changes in Earth's terrestrial surface include human-induced changes in land surface, which are important drivers of ecosystems' structure and function (Turner, Lambin, & Reenberg, 2007). Satellite-based imagery is increasingly used in monitoring such changes. Landsat-based thematic mapping images have been used to monitor and assess deforestation in the Amazon River basin (Potapov et al., 2014) and changes in vegetation cover in southern ItalyMancino, Nolè, Ripullone, & Ferrara, 2014).

Using geospatial data fusion in climate-related vulnerability assessments, Carrão and colleagues (2016) modeled and mapped global patterns of drought risk; they combined data about past and present, and at different spatial resolutions, on drought hazards, exposure, and vulnerability. Remotely sensed spatial imagery data on agricultural land was merged with ground-based data on precipitation, census-based data on population and livestock density, and survey-based data on drought-vulnerability indicators. Drought risk, they found, is higher for predominantly livestock-farming regions. This data-driven approach to assessing the spatial distribution of drought risk helps decision makers target the neediest areas for capacity-building interventions and drought-management policies.

Analyzing poverty is another area in which integration of remote-sensing data in data fusion can be applied to climate-change research. Annual demographic surveys, such as national censuses, often conducted at great expense, provide social data for tracking population growth and economic development trajectories, but accurate census data are often limited and inadequate despite their crucial role in poverty-alleviation efforts. In Angola, for example, there was a 40-year gap between national censuses (Watmough, Atkinson, Saikia, & Hutton, 2016). Poverty-mapping research methods extract socio-economic indicators from remote-sensing data and machine-based learning technology, and then calculate small-area poverty estimates (Xie, Jean, Burke, Lobell, & Ermon, 2016). Airborne and high-resolution satellite data also yield demographic data without expensive, time-consuming ground-based surveys. Similar approaches could pinpoint the location of infrastructure, economic sectors, population groups, and ecosystems that show the greatest risk of climate-related harm, and thereby identify vulnerable communities and micro-environments (Moss et al., 2013).

Big Data and the Quest for Real-Time Analysis

The use of geospatial Big Data, such as from cell phones and social media, which are available both during and immediately after extreme events, enables researchers and emergency responders to overcome spatial and environmental limitations of satellite imagery and aerial photography; those limitations include large-scale data resolution that hinders the detection of small flooded areas, and the obscuring of affected areas by clouds, smoke, dust, or debris.

Cell-phone data can reliably track human mobility and high-risk behavior after extreme weather events.

Real-time monitoring and assessment of climate-related disasters is another growing area of applied geospatial big-data research. Applications include real-time flood mapping, often locating floods at a very fine spatial scale (Graham, Poorthuis, & Zook, 2012; Li, Wang, Emrich, & Guo, 2017). Similarly, preliminary rapid assessments are made of the monetary value of disaster-related damages (Kryvasheyeu et al,. 2016). Social-media data also provide real-time, generally accurate feedback to decision makers and emergency-service providers. For example, to understand how Hurricane Sandy affected the U.S. East Coast in 2012, the combined spatiotemporal analysis of Twitter posts with Federal Emergency Management Agency (FEMA) household-assistance-grant data revealed a strong correlation between per-capita Twitter activity and per-capita disaster-related damage (Kryvasheyeu et al., 2016). Cell-phone data can reliably track human mobility and high-risk behavior after extreme weather events (Lu et al., 2016).

Federal Datasets, Related Resources, and Their Applications

Spatially explicit analyses of georeferenced data provide real-time feedback that is important for decision makers and emergency-service providers. Geospatial techniques reveal variation across space, which, when paired with other social and environmental variables, can illuminate patterns of climate vulnerability, resilience, and adaptive capacity across space and time. The contributions of geospatial data-fusion approaches demonstrate the long-term value of maintaining federally funded datasets in the long term.

The federal government collects and makes accessible vast amounts of spatial data. Recent efforts to expand coordination have been made through the Federal Geographic Data Committee. Such efforts have focused on establishing standards, coordination, and accessibility, through the Geospatial Platform, of federal geospatial datasets. Specific datasets rely on support from federal agencies. These include data underlying the Open Water Data Initiative (https://www.fgdc.gov/initiatives/open-water-data-initiative), which integrates federal, tribal, state, and local data and thus addresses present and future critical water resource needs. The baseline information in these and other datasets is often applied to mitigation and adaptation to changing resource availability.

Partnerships such as the National Flood Interoperability Experiment demonstrate the importance of data integration and the potential for crowd sourcing.

Important U.S. national data include population and demographic data from the Census Bureau and detailed landscape data from the National Oceanic and Atmospheric Administration and the U.S. Geological Survey. Partnerships such as the National Flood Interoperability Experiment—a joint effort among multiple U.S. government agencies (FEMA, the National Weather Service, the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, and the Army Corp of Engineers), the academic community, and select commercial partners—demonstrate the importance of data integration and the potential for crowd sourcing as a new tool to achieving real time landscape monitoring. For real-time solutions and for planning, National Flood Interoperability Experiment data can be leveraged by integrating with crowd-sourcing tools through Digital Globe's platform Tomnod (http://www.tomnod.com/), which solicits crowd-sourced data about natural disasters, fusing real-time GeoEye imagery with crowd landscape monitoring and interpretation. Registered volunteers can view imagery; mark locations of critical features, such as Hurricane Irma's damage to infrastructure; and provide near-real-time data for agencies such as FEMA that work with Digital Globe.

Research to date has only scratched the surface of potential Big Data applications to climate adaptation research and decision making (Ford et al., 2017). Data-fusion approaches combining large- and small-scale data have been used fruitfully to improve vulnerability assessments, provide bottom-up perspectives on successful adaptation processes, identify local trends, and yield further insights into the complexity of climate vulnerability (Shelton, Poorthuis, Graham, & Zook, 2014).

Sociology: Statistical Models for Integrated Analyses

Statistical modeling provides a common toolkit used across the social sciences and environmental sciences. Multivariate statistical models are well suited to the complex, multi-causal, and weakly determined nature of society-climate relations and other social phenomena. Applications (Marquart-Pyatt, Jorgenson, & Hamilton, 2015) include sociological studies of the socioeconomic drivers of GHG emissions—annual or decadal, and household to national scale (Jorgenson, Schor, & Huang, 2017; Rosa & Dietz, 2012;), and unequal social vulnerabilities relative to the impacts of pollution and industrial activities (Downey & Van Willigen, 2005). Studies also address social impacts of extreme climate-related events such as floods or heat waves (Harlan, Declet-Barreto, Stefanov, & Petitti, 2013) and recovery from failure of critical resources brought about by climatic variation compounded by over-exploitation (Hamilton, 2007). Additional concerns are the various scales of reactions to climate change, analyzed through coalitions among advocacy groups and networks (Caniglia, Brulle, & Szasz, 2015), U.S. funding organizations' finances (Brulle, 2014), and climate-change-related public opinion learned through large-scale surveys (Shwom et al., 2015).

Political views can modify or reverse the influence of education or science literacy and frequently outweigh the effects of local climate trends or weather.

Social data such as survey responses are useful in part because they can be merged with contemporary or cotermimous environmental measures or characteristics. Statistical models analyze interrelations between environmental factors and individual knowledge, perceptions (including policy support), or behavior. Spatial linkages between social and natural data are often analyzed by geographers.

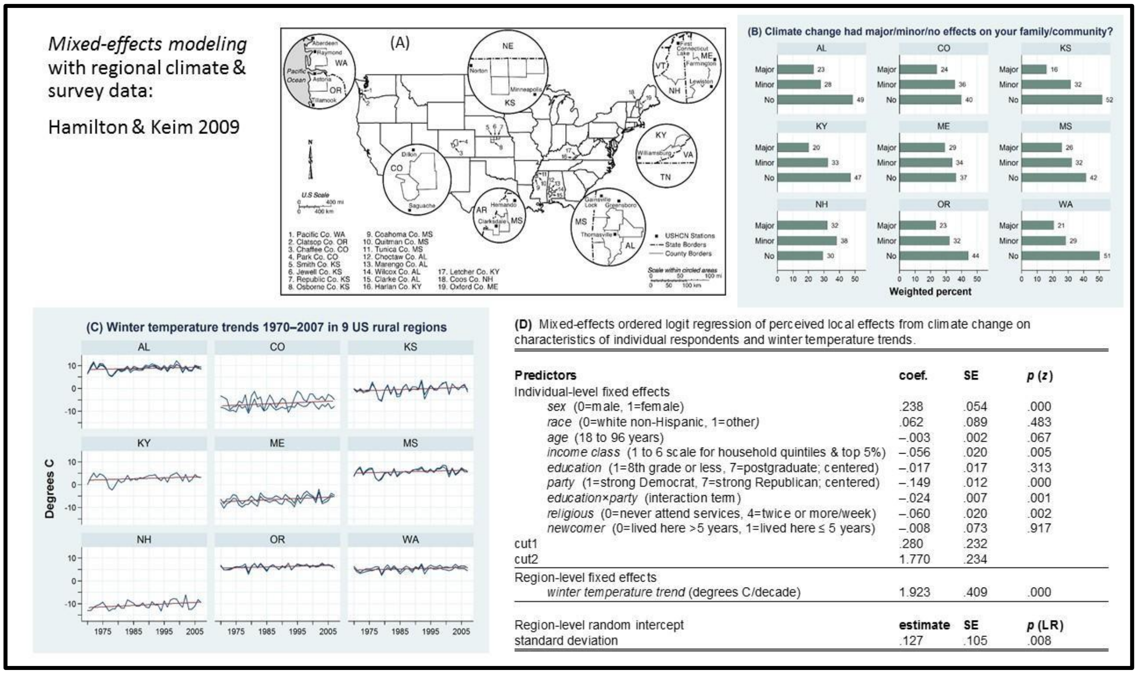
Public-opinion data often come from longitudinal surveys, such as the National Science Foundation-supported General Social Survey, Gallup Polls, or International Social Survey Program. Such surveys may include information on interview location, such as country, region, or state, and date, including single or successive occasions. Surveys targeting specific localities such as counties or metropolitan regions with large samples, sometimes created by pooling data from numerous regions, provide further avenues to integrate environmental data such as monthly or daily weather, extreme events, or remotely sensed land-cover and coastline changes. Data on health, economic activity, and polluting facilities provide contextual variables that may affect responses. Analyses of integrated natural- and social-science data have shown that environmental or climatic factors affect public beliefs, risk perceptions, or support for climate-related politics.

Integrated survey research reveals, in fact, that in the United States, political identification is the strongest predictor of individual views of climate change. Political views can modify or reverse

3. USE OF MIXED-EFFECTS MODELING TO STUDY RURAL U.S. RESIDENTS' OPINIONS OF CLIMATE CHANGE

A survey project conducted telephone interviews with almost 8,000 randomly-selected residents in nine U.S. rural regions. One question asked whether respondents thought that "global warming or climate change" had affected their community or family within the past five years. For each respondent, the interviews elicited background information including characteristics that could influence climate perceptions. Survey data were merged with climate-trend indicators derived from analysis of weather-station records in each region.

The authors fit a mixed-effects logit regression model predicting perceptions of global-warming impact from seasonal climate trends in each region, while adjusting for the effects of gender, race, age, income, education, political party, religiosity, and years resident in the area. The model also took into account non-climate region-to-region variations that reflect unmeasured but consequential factors such as local economy, history, and culture.



Predictors	coef.	SE	p (z)
Individual-level fixed effects			
sex (0=male, 1=female)	.238	.054	.000
race (0=white non-Hispanic, 1=other)	.062	.089	.483
age (18 to 96 years)	–.003	.002	.067
income class (1 to 6 scale for household quintiles & top 5%)	–.056	.020	.005
education (1=8th grade or less, 7=postgraduate; centered)	–.017	.017	.313
party (1=strong Democrat, 7=strong Republican; centered)	–.149	.012	.000
education×party (interaction term)	–.024	.007	.001
religious (0=never attend services, 4=twice or more/week)	–.060	.020	.002
newcomer (0=lived here >5 years, 1=lived here ≤ 5 years)	–.008	.073	.917
cut1	.280	.232	
cut2	1.770	.234	
Region-level fixed effects			
winter temperature trend (degrees C/decade)	1.923	.409	.000
Region-level random intercept	**estimate**	**SE**	**p (LR)**
standard deviation	.127	.105	.008

Figure 5. Mixed-effects modeling. Source: Hamilton and Keim (2009, p. 2349-2350, Figures 1, 2, 3). *5a*. U.S. rural locations surveyed. *5b*. Answers to question about personal effects of climate change. *5c*. U.S. regional winter temperatures. *5d*. Logit regression of perceived effects.

The study's primary finding was that perceived impacts of global warming were higher among people who lived in snow-country regions that had experienced winter warming. This effect remained significant after statistically controlling for individual characteristics and for otherwise-unexplained regional variations. Winter warming evidently made a stronger impression in snow country than in regions where winter conditions have less economic or quotidian salience. Perceptions of local climate change were influenced by respondent's sex, income, political party, education, and religiosity.

The influence of education or science literacy (Hamilton, Cutler, & Schaefer, 2012) and frequently outweigh the effects of environmental characteristics including objectively measured local climate trends or weather (Hamilton et al., 2016; Hamilton, Wake, Hartter, Safford, & Puchlopek, 2016; Marquart-Pyatt, McCright, Dietz, & Dunlap, 2014). Age, sex, and social identity also tend to be less consistently influential than politics is.

Among statistical modeling methods, ordinary least squares (OLS) regression is the most well-known method. Scores of other commonly used methods also accommodate models with measured, counted, and categorical variables; non-normal or otherwise problematic distributions; measurement errors; unobserved variables; mixed units of analysis; nonlinear, non-additive, or indirect effects; and spatial or temporal correlations among errors. Integration of social and environmental data takes place in geographically indexed datasets, time series, and panel formats that combine both kinds by using parallel time series from many locations. A suite of regression methods for multilevel or mixed-effects modeling estimates and tests effects of multiple predictors, operating across diverse regions and at different scales, such as parallel time series of physical and social variables (Marquart-Pyatt et al., 2015). Such methods have been applied successfully in sociological research including studies of human drivers of GHG emissions, and of public perceptions of and support for adaptation- or mitigation-related actions (Jorgenson et al., 2017; Marquart-Pyatt et al., 2014). Hamilton and Keim's (2009) study of social impacts of observed climate change or variation is discussed in Box 3.

Cultural Anthropology: Qualitative Research Methods

Qualitative research methods, including interviewing, conducting oral history, ethnography, and participant observation, are critical tools for global change research because they provide the rich detail and place-specific understandings of vulnerability, resilience, and adaptation that can support deep analysis. Such methods are particularly valuable in eliciting the meanings of climate-change-related experiences that influence behavior and in illuminating how context shapes actions, all of which can inform behavioral models and significantly reshape theories of action, belief, and causation (Maxwell, 1998). Qualitative researchers often use a participatory engagement framework with affected communities; at each stage of the research, from problem formulation through data collection to interpretation, this approach can inform evidence-based policy formation and the outcomes that will further affect those communities.

Qualitative research methods provide the rich detail and place-specific understandings of vulnerability, resilience, and adaptation that can support deep analysis.

Ethnography draws especially on the long-term, close observation of a community, culture, or other group. In doing so, ethnography provides insights into everyday lives, beliefs, perceptions, and activities. The methods and techniques used to create ethnographies constitute social and cultural anthropologists' foundational tool kit. "Being there," as Clifford Geertz (1988) explored, involves grounding research questions and methods in everyday experiences and local knowledge, and helps anthropologists understand connections among different systems and scales (Crate & Nuttall, 2009, 2016). Grounded research involves a necessary tension between local peoples' and the researcher's points of view; the former may correlate with indigenous or local knowledge and ways of knowing, and the latter with imposed scientific frameworks of understanding (Agrawal 1995). The participant observation method, established in the early 20th century by Franz Boas and Bronislaw Malinowski, has been called "a shibboleth for modern anthropology" because of that tension (Winthrop, 1991, p. 99). In addition to participant observation, qualitative techniques that inform ethnography include interviews, oral histories, focus groups, and archival research.

Qualitative research has proved especially valuable in climate change research in three significant ways. First, the data gained by qualitative techniques can show the importance of local meanings and ways of knowing. Second, qualitative methods reveal the importance of local and historical contexts, helping to explain lived experiences and perceptions, including those related to vulnerability, and connecting local experiences to regional systems through analyses of influence and power. Third, qualitative techniques used within a participatory frame engage community members in the creation of new knowledge as intentional researchers.

Furthermore, qualitative methods and their results offer climate-change policymakers important data that highlights cultural meanings linked to climate adaptation (Adger, Barnett, Brown, Marshall, & O'Brien, 2013). These data include, for example, information sharing between affected indigenous peoples and local communities, such as through the Many Strong Voices Programme (http://www.manystrongvoices.org/); interactions among and motives of corporations and policymakers (Lahsen, 2010); and the ways people understand specific policy-application instruments such as carbon offsets (Fiske, 2009).

Illuminating Local Meanings

Information gathered through field research helps social scientists understand not only what people believe or want but also why and how their beliefs or desires connect to specific domains of their lives, such as religion, health, and family. Such fine-grained data complement Big Data by providing necessary explanatory detail about specific places, contexts, and experiences. Qualitative data, when paired with other kinds of data, including climatological measurements and large-scale surveys, provide nuances and meanings that are often missing from quantitative findings. Ethnographic techniques help researchers learn about local needs, experiences, and perspectives that often differ from dominant systems of knowledge and governance.

Individuals and households had intimate local knowledge about changes in their immediate environment but lacked locally contextualized information about the effects of climate change.

Ethnographies have documented conditions in coal-mining communities, including deteriorating health and related social protests (Bell, 2013). Others have explored experiences with emotionally distressing experiences, whether during slow-moving climate changes (Norgaard, 2011) or a deadly U.S. heat wave (Klinenberg, 2002). Some narratives emphasize inequality for rural African American communities across the southern United States, while others document women's global experiences of climate disasters (Bullard & Wright, 2012; Nagel, 2016).

Researchers use discourse analysis and cultural models to investigate how people talk and otherwise express their thoughts about ideas and processes, not only about human-environment interactions and climate change but also about science. A critical view of science questions how and by whom science is conducted, and how scientific research and conclusions act as instruments of power (Fiske et al., 2014, p. 15). In interviews and other texts, scientists analyze connections between ideas and understandings that influence groups' experiences and actions, how framing or presenting an issue affects decision making, how underlying values shape beliefs about policies, and ways in which science practices are supported by historically and culturally informed frames and values. Studies of consumption examine reasons that people make particular consumer choices that would improve or damage sustainability (Warde, 2017). Consumption studies emphasize the dependence of consumers' purchases and energy use, embedded in status-conscious lifestyles, on social reference groups (Earhardt-Martinez & Schor, 2015). Interview data also reveal associations among personal relationships, trust, framing, and cultural beliefs that influence denial and acceptance of climate change (Arbuckle, Morton, & Hobbs, 2015; Stoll-Kleemann, O'Riordan, & Jaeger, 2001).

Ethnoclimatology, the study of culturally based ideas about climate, has generated studies of power dimensions including differences between local knowledge and climatological models regarding meaningful aspects of change (Vedwan & Rhoades, 2001). One such issue is what constitutes adequate or excessive precipitation (Box 4).

The Sakha research illustrates how collaboration between communities and social scientists, which is especially effective when built into the project design, facilitates the integration of different points of view and data types. Along with the increasing impact of climate change, the value of qualitative techniques for gaining in-depth detail; understanding beliefs, impacts, adaptations, and strategies about climate change; and matching policies to local, cultural needs, preferences, and institutions also will increase.

In relation to the second contribution, how context influences actions and experiences, qualitative research can help policymakers understand contextually influenced variations in vulnerability, resilience, and adaptation. Understanding such variance can highlight both place-specific issues and differences among communities. Context-specific information for such factors is valuable in distinguishing local-level characteristics. Analyses of vulnerability, for example, often describe household or individual resources, social network connections, and exposure to a specific risk or set of risks. What counts as a resource, connection, or exposure varies within and across communities. For some populations, in providing access to resources, connections that may seem weak, such as with an acquaintance rather than a close friend, can be more important than those usually deemed strong (Grannovetter, 1973). Knowing how communities and individuals understand concepts in turn will help clarify what vulnerability means; similarly, with qualitative methods, researchers learn about specific contexts, including underlying social conditions, that can affect vulnerability, and thus reduce barriers to climate change adaptation, especially when local knowledge, experience, and governance are incorporated (Wise et al., 2014).

Social science, with decades of research experience on disasters, underscores the importance to climate-change impacts of the cultural and social dimensions of vulnerability, resilience, and adaptation; those dimensions include both threats to the cultural and social aspects of human life and the cultural and social dimensions of responses and adaptation to climate change and related threats (Adger et al., 2013; Hackmann, Moser, & St. Clair (2014). To formulate effective

4. Sakha people and climate change in Siberia

A collaborative interdisciplinary research project explored local effects of climate change in the Sakha Republic's Viliui regions in northeastern Siberia, Russia. In the post-Soviet context, rural Sakha people practice horse- and cattle-breeding subsistence, or a "cows-and-kin" adaptative mode (Crate, 2006). In the extreme climate, with annual temperatures ranging from -60 C in winter to +40 C in summer, two tons of hay per cow are required for winter fodder. Householders are outspoken about the increasing challenges of local climate-change effects. Collaborating with four communities, Susan Crate investigated the changes that inhabitants reported: winters were not as cold, summers were not as hot, rain patterns had changed, and seasonal timings were off. Sakha elders especially explained that the Bull of Winter was no longer arriving; this mythological beast holds the climate in an extremely cold, dry, snowless 3-month cycle (Crate, 2008). Such explanations showed how much their local way of knowing persisted. Focus groups, interviews, and surveys yielded data showing that individuals and households had intimate local knowledge about changes in their immediate environment but lacked locally contextualized information about the effects of climate change. Collaboration between Crate and Alexander Fedorov, a scientist investigating the regional permafrost, facilitated exchanges in which local inhabitants' knowledge and observations were shared and were informed with Fedorov's findings about climate's direct local effects, including the degradation of permafrost that altered familiar landscapes and increased water on the land (Crate & Fedorov, 2013a, 2013b).

One of inhabitants' common assessments was that there was "too much rain." However, when their observations were compared with instrumental recordings, a 20-year precipitation record showed no sizeable increase in rainfall. Instead of discounting inhabitants' claims, Crate used social scientific logic and inquired further. Having worked with Sakha people since 1991, she knew that subsistence depended on rain at the right times. This insight soon revealed the answer: both the instrumental and the community records were true. What was affecting Sakha subsistence was a seasonal pattern change: There was less rain in the spring, when it is critical for growing hay, and more in July and August, when it spoils the hay. Such integrated, contextualized analyses of social and biophysical perspectives using qualitative and quantitative data powerfully reveals how vulnerability, resilience, and adaptation to global climate change all shape ecological and cultural systems in place-specific ways.

responses and innovative, feasible and acceptable solutions, "we now need framings that foreground the social, political, economic and cultural nature of climate change, and prioritise people's beliefs and values, their behaviors, practices and the institutions that guide them," Hackmann and colleagues (2014, p. 655) remind us.

By the turn of the 21st century, when climate change emerged as an interdisciplinary research field, environmental social scientists had already been investigating precursors of the global environmental crisis, including environmental injustices related to industrial activity and growth. Sociological studies examined the energy industry and other resource-extraction industries, addressing such issues as the negative social impacts of rapid economic growth on U.S. rural mining communities (Freudenburg, 1984). Others considered the siting of toxic facilities and dumping of industrial waste in African American, Hispanic, or Native American communities throughout the United States (Bullard, 1990; Mohai & Bryant, 1992), and other environmental burdens that disproportionately affected minorities and the poor. Anthropologists investigating such topics produced numerous ethnographies that draw on local knowledge, as discussed by

Fiske and colleagues (2014, p. 61). Because vulnerability, resilience, and adaptation are deeply influenced by their social contexts, social scientists increasingly assess adaptive capacity by using flexible approaches that integrate multiple types and sources of knowledge, including stakeholder knowledge and expert experiences of context (Richards et al., 2013). Recent meta-analyses of climate-change studies reveal the most salient themes and common elements of these investigations of climate-change knowledge, vulnerabilities, and adaptations (Adger et al., 2013; Barnes et al., 2013; Head, Gibson, Gill, Carr, & Waitt, 2016).

The third crucial contribution concerns participatory engagement, as qualitative research is well suited to strengthening relationships between local populations and social scientists. Collaborative research processes can lead to greater local investment in developing new programs and policies, or in responding to the existing ones in which they had not been involved. Early community involvement in participatory engagement can help researchers ask the right questions about local conditions, collect data that are appropriate to local contexts and reflect diverse experiences, and make recommendations that suit local conditions and constraints (Pearce et al., 2009). Participatory engagement can also lead to capacity building that can strengthen community resilience and adaptive capacity (Mapfumo, Adjei-Nsiah, Mtambanengwe, Chikowo, & Giller, 2013). The well-documented value of participatory engagement for policymaking includes environmental management, regulation, and adaptation. Reviewing 20 years of co-management, Berkes (2009) emphasizes learning and adaptive problem solving. Pahl-Wostl and colleagues (2007) highlight the value of participatory management for addressing climate-change-related uncertainties in complex systems. While participatory engagement often requires a substantial time investment, the resulting strategies will likewise be long lasting (Pearce et al., 2009).

Because the impacts of climate change are place specific and path dependent, there is uneven exposure across and within communities. Through translation, mediation, and facilitation, social scientists work with communities to identify and promote strategies that are culturally appropriate and equitable. These methods, summed up under “community-based participatory research,” involve partnerships between communities and researchers in defining relevant research problems, collecting and analyzing data, and interpreting results in ways that empower and benefit communities (Durkalec, Furgal, Skinner, & Sheldon, 2015). Increasingly, through engaging more fully with participants, social scientists are improving research by making it more relevant to local knowledge and needs, and increasing the relevance of proposed solutions or policies—all based in recognition of the power relationships inherent in research activities (Schensul & LeCompte, 2016; Smith, 1999; Whiteford & Vindrola-Padros, 2015). These power relationships include decision making and the limits to public participation, note Few, Brown, and Tompkins (2007), who suggest focusing on specific outcomes, especially reducing vulnerability and on promoting transparency about the limits of bottom-up long-term planning.

The Southeast Climate Consortium and the Florida Climate Institute developed a long-term, successful participatory engagement project that brought together farmers, extension agents, climate scientists, and other researchers (Bartels et al., 2013). Their interactions led to improved understanding of climate risks, stronger relationships among participants, and increased awareness of available strategies. To explore the history of southeastern U.S. agriculture and climate change, the teams together developed an interactive, story-based timeline; imagined numerous possible futures and their implications through scenario-based discussions of threats and strategies; and created an adaptation exchange to share farming-related strategies and impacts (Bartel et al., 2013).

Communicating about climate change also benefits from participatory engagement (Moser, 2014). A particularly challenging aspect of research translation is the communication and interpretation of the inevitable uncertainties of research. Another challenge is determining the broad, real-world applicability of very specific, laboratory-produced results. Guiding users of the information through the uncertainties of translation and their impact on confidence in such real-world applications is a critical component of building the users' trust and acceptance of science-based advice. Being as transparent as possible about important assumptions and limitations builds trust and allows for important dialogues to occur about the degree to which the research results can effectively inform decisions.

In sum, qualitative methods including participant observation and conducting interviews and surveys can be extremely valuable for learning local perspectives and meanings, understanding how context influences experiences and expectations, and strengthening engagement between local communities and outsiders. For climate change, all this can lead to improved understanding of people's ideas about adaptation strategies, differing experiences related to social and cultural contexts, and potential partnerships that can help communities effectively adapt to changes. Qualitative methods and techniques, including ethnography and participatory engagement, are increasingly paired with other social-science and natural-science methods to bring meanings and context into analyses. Close attention to the ways that different kinds of knowledge and different perspectives have been, and can be, brought together is likely to continue to lead to successful studies.

Conclusion

Rising sea levels would be of less concern did large numbers of people not reside near seashores. Climate-driven variability in agricultural production would be less worrisome if the world maintained itself well below carrying capacity. There would be less climate-driven migration if human actions did not drive climate change. Because many global problems are human-made, however, social science tools are crucial for identifying and coping intelligently with our challenges.

Throughout this paper, we have demonstrated how the use of social science tools, methods, and analyses has enhanced climate-change research; has provided accessible syntheses to inform decision making; and will continue to do both. To understand socio-ecological systems—linked systems of people and nature—we need integrated analyses of diverse qualitative and quantitative datasets. Integration of these datasets allows investigation of not only what is happening—that is, physical climate change—but also why and how, as in the way a social or cultural factor contributes to a specific impact; integration also provides robust information for scenario modeling. Throughout the paper, we have also shown how social scientists have conducted integrated fundamental research and translated that research into actionable knowledge that leads to policy or technology solutions and accounts for unintended consequences. In this concluding section, we first review the key insights from our discussion of methods, tools, and analysis, and then present future directions in which research might proceed.

Key Insights

The past can provide meaningful lessons. Social-scientific study is an especially significant dimension of learning about the past. The archaeological record provides a long narrative of human-environment interactions and reactions, presented here as a Distributed Observing Network of the Past—a powerful way to conceive of this transdisciplinary record. Every feature in an archaeological site is an observing point, across time and space, where natural and human systems interact and leave proxy records, or evidence of those interactions. Those records bridge disciplines by drawing from faunal, botanical, geological, and cultural data, and help answer fundamental questions about the ways human habitation and action have interacted with the environment.

Archaeological tools, methods, and analyses are significant as well in supporting unique comprehension of the complexity of human resource management and use, including resource depression. Intersections among resource depression and climate perturbations often have had unintended consequences, which then have led to fundamental changes such as mass migration and even system collapse. Archaeology's evidence-based insights and cautionary lessons can make important contributions to scenario building and modeling that help anticipate future events.

The geospatial techniques we have presented include new tools and methods in geospatial fusion, which can integrate or layer Big Data with remote datasets. Such a data-driven approach has proved essential in addressing numerous core topics, such as valuing carbon dynamics, identifying socioeconomic and biophysical determinants of vulnerability and adaptive capacities, monitoring land-use and land-cover change, and assessing biodiversity loss and conservation outcomes. Particularly promising seems the integration of Big Data obtained from social media with geospatial tools, as it helps researchers overcome limitations of satellite imagery and aerial photographs, and conduct real-time analysis that can help infuse short-term perspectives into emergency responses to or long-term disaster monitoring. More generally, using geospatial tools and analyzing the data they generate can provide insights into local trends and generalizable patterns in climate variability.

Statistical modeling is central to the social-science toolkit, as modeling aids understanding of complex, coupled social and environmental phenomena by integrating social and environmental data. Studies using modeling have addressed social and political identity, the socioeconomic drivers of greenhouse gas emissions, unequal vulnerability, loss and recovery of critical resources, and the impact of climate-change events including human reactions to them.

To delve deeper into choices, perception, and meanings, qualitative methods help provide important insights at the individual and community levels. The related techniques especially aid in comprehending local meanings and contexts, and help community members create new knowledge. Qualitative research, therefore, is especially helpful to climate-change policy makers, who need to understand the cultural meanings and motivations for behavior linked to climate adaptation, including community decision making about and interpretation of policy instruments. Participatory engagement—often enhanced through qualitative research—is especially significant because it tells us what people think about climate change or adaptation strategies, and how their experiences differ at varying scales, and so informs potential future partnerships in adaptation strategies.

In sum, social science research offers many, diverse instruments for data collection and for understanding system responses. It also provides a wide range of methods for analyzing and interpreting data, including textual analysis, statistical modeling, and geospatial analysis, often effectively combined in collaborative interdisciplinary research.

Future Opportunities

Future social science research could examine ways of incorporating interdisciplinary methods into improving our understanding of the interactions between human and natural systems under global climate change. That research is crucial for policy development and application. The likely success of future policies will depend on incorporating context into policymaking through paying greater attention to place-specific experiences and increasing community engagement in research and the decisions that emerge from the research. Our presentation of important tools, methods, and analyses leads to the following specific areas in which they promise to especially useful. These ideas are far from all inclusive. Along with the tools, methods, and analyses we have presented, we encourage social scientists to develop additional tools for identifying and coping intelligently with these challenges.

Knowing the “right” social science discipline will encourage successful in future projects. While social science disciplines often share theoretical paradigms, methods, and tools, each discipline is also distinct in terms of the questions it asks, and the data and methods it uses. Understanding the potential of scientific collaboration requires some understanding of each discipline’s characteristic questions, data, and methods. Fruitful collaborations will rely on posing over-arching research questions more than on reiterating the need for such collaboration. As we have noted, the archaeological record supports insights into the relation between uncertainties and technological innovation, while integrating statistical modeling methods with spatial data can improve models of local conditions. We see an increasing role for boundary organizations, both in identifying central questions and stakeholders, and coordinating the engagement of a broad array of social science disciplines with problem-oriented activities.

Translation and synthesis activities can be further emphasized. One crucial step in interdisciplinary and inter-organization coordination is effective translation at all levels and during all stages, beginning at the problem identification stage and including the development of a shared epistemology. Assessments of collaborative projects should systematically convey important messages accessibly—reducing or removing scientific jargon; presenting the simplest versions of complex ideas, models, and results; connecting with stakeholders’ knowledge; and synthesizing results across a range of studies—all of which will support effective incorporation of decision-making tools. Communication about plans and policies, with the goal of transparency, could include more attention to the uncertainty of outcomes.

Increasing social science input into scenario building would be beneficial. Scenario analysis is effective for synthesizing research findings across disciplines, including via joining different ideas and disciplinary models. Scenario analysis facilitates communication and helps translate research into actions. Such analysis generates crucial drivers for change and logical narratives around themes, principles, and assumptions—all of which provide a plausible, consistent, logical underpinning to the scenarios. Future developments in the use of scenario analysis will increasingly relate to the social drivers of change and will help in understanding how those connect to natural drivers, often through application of specific disciplines and through joining natural and social sciences. Such analyses will be ever more crucial to understanding decision making, especially if it seems irrational, and thus aligning planning objectives with expected outcomes. Combined use of qualitative and quantitative methods will most effectively generate scenarios and explore their implications.

Community engagement will draw on qualitative and quantitative methods. To understand and shape responses to climate change, it will be increasingly important to use federal datasets along with strategies for enhancing partnerships across federal, state, local, and organizational boundaries. As climate-change effects are often harshest in remote locations with underserved populations such partnerships will be central to community planning efforts. Successful planning will rely on the inclusion of community inputs and perspectives at all stages. In advance of data collection, using social-science perspectives to help understand different modes of communication and the availability of diverse communication resources will improve the reliability of the data collected and the likelihood that it reaches all corners of the country. Integrating ethnographic techniques and data derived from other qualitative and quantitative methods can provide insight into the roles of social identity and local context and meaning.

Federally supported survey data are also crucial to future interdisciplinary climate research. These include data from long-term and longitudinal surveys that measure changes in attitudes and behaviors related to environmental change over time and can provide insights into the efficacy of incentives and disincentives. Of continuing importance will be the Federal Geographic Data Committee’s ongoing standardization and curation of large geospatial datasets that underpin future monitoring of changing land use. Increasing benefits will come from new efforts at enhanced real-time and longitudinal crowd-sourcing. These results will be important parts of the geospatial Big Data that could be routinely used in investigating climate-related impacts on human activity. New and expanded partnerships between federal, private, academic, state and local organizations would make the most of these new tools and federally maintained datasets.

In sum, future social science research will draw on knowledge of the past to shape future decisions; utilize and integrate quantitative and qualitative methods; and depend on collaborations among research teams, communities, and policymakers. The development of a set of tools and best practices for creating and maintaining not only data but ongoing relationships will in turn generate more case studies and long-term assessments of community engagement in policymaking, and increase successful short-term adaptation and long-term planning.

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Context Statement

This white paper is a product of the workshop "Social Science Perspectives on Climate Change" held in Washington, DC in March 2017. Two other white papers resulted from the workshop:

> D. Hardy, H. Lazrus, M. Mendez, B. Orlove, I. Rivera-Collazo, J. T. Roberts, M. Rockman, K. Thomas, B. P. Warner, R. Winthrop. (2018). Social vulnerability: Social science perspectives on climate change, part 1. Washington, DC: USGCRP Social Science Coordinating Committee. https://www.globalchange.gov/content/social-science-perspectives-climate-change-workshop.
>
> S. Fiske, K. Hubacek, A. Jorgenson, J. Li, T. McGovern, T. Rick, J. Schor, W. Solecki, R. York, A. Zycherman. (2018). Drivers and responses: Social science perspectives on climate change, part 2. Washington, DC: USGCRP Social Science Coordinating Committee. https://www.globalchange.gov/content/social-science-perspectives-climate-change-workshop.

The workshop was organized by the U.S. Global Change Research Program's (USGCRP) Social Science Coordinating Committee (SSCC) in cooperation with the American Anthropological Association, the American Association of Geographers, the American Sociological Association, and the Society for American Archaeology. The workshop had three aims:

- demonstrate how the social sciences can add important methods, perspectives, and data to climate change mitigation and adaptation efforts;
- enhance collaboration between academic and federal social scientists, and between natural and social scientists; and
- develop products that support the Fourth National Climate Assessment, USGCRP's Interagency Working Groups, and federal agencies.

The USGCRP, a confederation of the research arms of 13 federal departments and agencies, is charged with advancing global change science, coordinating federal research on global change, and producing a quadrennial National Climate Assessment. "Global change" as used here includes change involving climate, land use and land cover, atmospheric circulation, the carbon cycle, biodiversity, and other planetary-scale physical and biological systems, and the ways these phenomena are shaped by social systems.

The USGCRP's Social Science Coordinating Committee is charged with promoting the integration of the methods, findings, and disciplinary perspectives of the social and behavioral sciences into federal global change research. This goal was laid out in the USGCRP's 2012–2021 Strategic Plan, which led to the establishment of the Committee in 2014. The Committee is broadly multidisciplinary, and has included social scientists from archaeology, cultural anthropology, economics, geography, human ecology, political science, science and technology studies, social psychology, and sociology.

The workshop brought together about 30 academic, environmentally focused social scientists from archaeology, cultural anthropology, human geography, and sociology, with some 60 federal staff involved in climate change-related activities. Each of those disciplines has developed a large body of research on the human dimensions of climate change that can complement federal climate change research, but is not often considered. The March 2017 workshop focused on three themes: identifying innovative tools, methods, and analyses to clarify the interactions of human and natural systems under climate change; describing key factors shaping differences in social vulnerability to climate change; and providing social science perspectives on drivers of global climate change.

The themes were identified in advance of the workshop by the SSCC and representatives from the four participating associations. The associations, in turn, recruited scholars from their disciplines to serve with SSCC members on interdisciplinary writing teams for each of the themes. The teams prepared preliminary drafts for use in the March 2017 workshop. There the writing groups met with federal participants, who offered reactions and ideas for improving the white papers. They have been extensively revised since the workshop.

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